SELECTIVITY OF GILL NETS ON ESTUARINE AND COASTAL FISHES FROM ST. ANDREW BAY, FLORIDA

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ABSTRACT

Eleven gill nets, each of a different mesh size, were fished 126 days from 4 April to 29 December 1973 in St. Andrew Bay, Fla. Of the estuarine and coastal fishes that were caught, 22 were in numbers sufficient to evaluate the relation between length of fish and mesh size. Mean length increased with an increase in mesh size for 20 species. Ten species—gulf menhaden, *Brevoortia patronus;* spot, *Leiostomus xanthurus;* sea catfish, *Arius felis;* pinfish, *Lagodon rhomboides;* Atlantic croaker, *Micropogon undulatus;* blue runner, *Caranx crysos;* pigfish, *Orthopristis chrysoptera;* bluefish, *Pomatomus saltatrix;* Spanish mackerel, *Scomberomorus maculatus;* yellowfin menhaden, *B. smithi*—were caught in sufficient numbers to apply and evaluate the normal probability model to define gill net selectivity. One or more of the three assumptions—normality of selectivity curve, linearity of mean length-mesh size relation, and constancy of standard deviation between mesh sizes—inherent in the model was violated by the data for each species to which the model was applied except Atlantic croaker and blue runner. Useful information was provided, however, in relation to evaluating mesh-size regulations and for determining mesh sizes for increasing capture efficiencies in gill net fisheries.

Rarely will a particular type of fishing gear capture all sizes of a species of fish with equal probability. Gill nets are selective in that, for a particular species and mesh size, fish are retained with high probability at certain lengths and with decreasing probability for larger and smaller individuals. Most streamlined fish without projecting spines, teeth, or opercular bones are caught in gill nets by becoming tightly wedged or enmeshed in the webbing. To describe selectivity for these streamlined fishes, a smooth unimodal curve with capture probabilities descending to zero is suggested by several workers (Regier and Robson 1966). Fish species that are not streamlined, or that have stiff projecting appendages or spines, are frequently caught entangled in the webbing rather than, or in addition to, becoming wedged in the meshes. For these species skewed or multimodal curves are usually necessary to describe capture probabilities (Hamley and Regier 1973).

An understanding of the selection properties of gill nets is necessary to evaluate catch statistics, alter catch per unit effort, and regulate the sizes of caught fish. Most methods of estimating recruitment, growth, sex ratio, and survival of a fish species require samples that are representative of the population in respect to size of individuals. Only if size selectivity of the fishing gear is known can the catch statistics be adjusted and used to provide correct estimates of the parameters of interest (Cucin and Regier 1966). Alternatively, an understanding of how selectivity depends on the characteristics of the gear may be used to design a series of gear to yield samples of known characteristics over a specified size range (Regier and Robson 1966). A knowledge of the size selective properties of the gear permits recommendations of mesh sizes to maximize (increase capture efficiency) or minimize (protect from harvest) the catch on certain sizes and species.

Published information is not available on the lengths of fish caught in particular mesh sizes of gill nets for estuarine and coastal fishes inhabiting the Gulf of Mexico except for a meager amount on two species. Klima (1959) reported length-frequency distributions of Spanish mackerel, *Scomberomorus maculatus,* that were caught in 7.9- and 9.0-cm stretched-mesh gill nets. Modal lengths of those were 37 and 43 cm, respectively. Tabb (1960) reported a length-frequency distribution of spotted seatrout, *Cynoscion nebulosus,* that were caught in 8.0-cm stretched-mesh gill nets. Modal length of the distribution was 33.5 cm.

Mesh sizes of gill nets most frequently used to capture various species of fish in the commercial gill net fishery in Florida were reported by Siebenaler (1955).

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The objectives of this study for each species caught in sufficient abundance were: 1) to show the relations between mesh size and the mean length and standard deviation in length of fish, 2) to define gill net selectivity by applying the normal probability model, 3) to evaluate the applicability of this model for defining selectivity, and 4) to discuss uses of the derived information.

STUDY AREA

The study area was in the St. Andrew Bay system located in northwest Florida along the Gulf of Mexico. This bay system, compared to most other northern gulf estuarine systems, is deep, has high salinities, low freshwater inflows, large areas of submerged marine grasses, low turbidities, high percentages of sand in the substrate, and has fish and crustacean faunas typical of both coastal and estuarine areas (Ichiye and Jones 1961; Hopkins 1966; Brusher and Ogren 1976; May et al. 1976; and Pristas and Trent 1977). The diurnal range of the tide in the St. Andrew Bay system is about 0.5 m.

ASSUMPTIONS

The relation between the mesh size of gill nets and the size of captured fish can be determined by setting a series of gill nets that vary only in respect to mesh size if certain precautions are taken and certain assumptions are valid. Fishing effort must be equal among mesh sizes, i.e., assume all fish of a given length are equally likely to encounter all nets. This means damage to each net must remain low or about equal among mesh sizes, and net locations are equal in respect to the probability of a net catching a particular fish. We must assume that no "gear saturation" occurs, i.e., the number of fish already entangled in the net in no way influences subsequent behavior of other fish and the net, and that no "spill-over" occurs, i.e., large fish do not lead along the nets until they encounter a large enough mesh in which perhaps to become enmeshed or entangled (Regier and Robson 1966). We must further assume that loss of fish from the nets through predation is not dependent on mesh size or the size of fish.

GEAR AND METHODS

Eleven gill nets, each of a different mesh size, were fished for 126 days from 4 April to 29 December 1973 at a location about 400-1,000 m northwest of Courtney Point in St. Andrew Bay. From 4 April through 20 September, the nets were set every 14th day and fished for 72 consecutive hours. From 20 September, the nets were fished continuously until 13 December. The nets were set again on 26 December and fished for 72 h. Nets were anchored about 50 m apart parallel to each other, perpendicular to shore, and in water depths of 2.2 to 2.6 m (mean low tide). Nets were randomized among net location each time the nets were set. During the continuous fishing in the autumn, the nets were randomized among locations twice during each 2-wk period. Net damage to each net was maintained below 10% of the total surface area.

Increments of mesh sizes in the series of fished nets were small, so that widely overlapping ranges of fish lengths would result. Mesh sizes used in this study were chosen to catch the more abundant species frequenting the St. Andrew Bay area (Pristas and Trent 1977). Stretched-mesh sizes ranged from 6.35 cm (2.5 inches) to 12.70 cm (5.0 inches) in 0.63-cm (0.25-inch) increments.

The nets were 33.3 m long and 3.3 m deep. They were made of #208 clear monofilament (0.33 mm diameter, filament break strength about 26.4 kg) nylon webbing. The webbing was hung to the float and leadlines on the half basis (two lengths of stretched webbing to one length of float or leadline, i.e., a hanging coefficient of 0.5).

Fish were removed from the nets between 1 h before and 2 h after sunrise and occasionally between sunset and 1 h after. The total numbers of each species, including damaged specimens, were counted. Lengths of undamaged specimens were measured to the nearest 0.5 cm. Fork length (tip of snout to fork of tail) was measured for those fishes having forked tails and total length (tip of snout horizontally to extremity of the caudal fin) was measured for Atlantic croaker, *Micropogon undulatus*, and sharks.

Length-frequency distributions of the catch by species and mesh size, based on the number of fish that were measured, were adjusted to represent the number of fish that were caught (those measured plus those damaged), so that the number making up each distribution represented catch per unit effort for each net.

MODEL FOR DETERMINING SELECTIVITY

Basic mathematical models, or modifications of basic models, for describing selectivity of gill nets were proposed by Baranov (as described by McCombie and Fry 1960), Olsen (1959), McCombie and Fry (1960), Gulland and Harding (1961), Ishida (1962), Holt (1963), Regier and Robson (1966), Hamley (1972), and Hamley and Regier (1973). Ten methods of describing selectivity were used by the above authors. Except for the DeLury method described by Hamley (1972), the mathematics and details of application of these methods were discussed by Regier and Robson (1966).

A comprehensive review of gill net selectivity was presented by Hamley (1975). All basic models, applications and shortcomings of these models, and the variety of factors (thickness, materials, and color of net twine, hanging of net, and methods of fishing) that must be considered in determining selectivity were discussed.

The method proposed by Holt (1963) was used to evaluate selectivity on species that were caught in this study. Holt assumed that: 1) the selectivity curve would take the form of a normal frequency distribution; 2) the efficiencies of two nets with different mesh sizes would be similar for fish of their respective mean lengths; and 3) the standard deviations of the distributions for two different mesh sizes would be equal. The equations for evaluating the above assumptions and for describing selectivity have been given by Holt (1963), Regier and Robson (1966), and Hamley (1975).

If Holt's three asssumptions are analyzed and deemed acceptable, points of the selectivity curve for mesh size m_i can be computed by

$$s_{ij} = \exp\left[-\frac{1}{2s_i^2}(l_j - \bar{l}_i)^2\right]$$

where l_j = length of fish in length stratum j
$\bar{l}_i$ = mean selection length
s_i = standard deviation of the selectivity curve
n_{ij} = number of fish of length l_j caught in net m_i.

Then n_{ij}/s_{ij} can be used to estimate abundance of fish for each l_j and therefore, the length-frequency distribution in the fished population can be estimated from the length-frequency distribution obtained from fishing a particular mesh size on the population.

An additional assumption is necessary if catches from a series of nets with different mesh sizes are combined and used to estimate the length-frequency distribution of the fished population. The assumption is that the selectivity curves for all meshes have the same shape (each s_i is an estimate of a common s) and amplitude (each net fishes with equal efficiency on the length at which the net is maximally efficient). This assumption was questioned by Ricker (1947), Ishida (1964), Regier and Robson (1966), and Hamley (1972). The assumption can be tested only if the length-frequency distribution of the fished population is known. Hamley and Regier (1973) tested this assumption on walleye, *Stizostedion vitreum vitreum,* which were tagged prior to being recaptured with gill nets, and found that the shapes and amplitudes of their selectivity curves changed with mesh size. This assumption could not be tested in our study.

Information derived from a selectivity study has various uses depending upon the validity of the mathematical model used to describe selectivity and on the accuracy and precision required. The model can be useful for some purposes even if all the assumptions are not met or even if the model is not the most accurate and precise one for describing the empirical data.

The objective of most selectivity studies has been to determine the most appropriate model for describing gill net selectivity for a single species of fish (Regier and Robson 1966). In this study we have attempted to provide as much information as possible about gill net selectivity on 22 species. To 10 of these we applied a single mathematical model and either accepted or rejected the model in relation to each of several potential applications. By accepting the model we do not infer that it is the most accurate or precise model but that the approximation to the data is sufficiently close and accurate to be useful.

NUMBERS AND MEAN LENGTHS OF FISHES SELECTED FOR ANALYSES

Of the 76 species that were caught in the study area during 1973 (May et al. 1976; Pristas and Trent[2]), 22 species had catches exceeding 100 specimens. Of the 22 species, 15 were commercially important in gill net fisheries in one or more states along the south Atlantic and Gulf of Mexico

[2]Pristas, P. J., and L. Trent. 1976. Seasonal abundance, size, and sex ratio of fishes caught with gill nets in St. Andrew Bay, Florida. (Unpubl. manuscr.)

coasts (National Marine Fisheries Service 1974). Number caught (n_i), number measured (nm_i), mean length ($\bar{Sl}_i$), and standard deviation (Ss_i) of mean length for each of the 22 species by mesh size are shown in Table 1.

The assumption that mean lengths of fish that

TABLE 1.—Number of fish caught (n_i), number measured (nm_i), mean length in centimeters ($\bar{Sl}_i$), and standard deviation of length (Ss_i) by stretched mesh size (m_i) and species.

		m_i in centimeters and (inches)										
Species		6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)	10.2 (4.0)	10.8 (4.25)	11.4 (4.5)	12.1 (4.75)	12.7 (5.0)
Gulf menhaden,[1]	n_i	726	897	1,339	845	411	99	14	10	3	9	16
Brevoortia patronus	nm_i	696	830	1,062	787	342	89	14	8	2	6	10
	$\bar{Sl}_i$	17.4	19.7	21.3	22.1	22.9	23.7	22.7	23.3	26.0	21.0	22.0
	Ss_i	1.0	1.4	1.1	1.1	1.3	1.4	2.4	3.2	0.7	1.3	1.5
Spot,[1]	n_i	1,830	1,054	172	27	10	0	1	2	0	0	0
Leiostomus xanthurus	nm_i	1,511	942	162	27	7	0	1	2	0	0	0
	$\bar{Sl}_i$	19.2	20.3	21.6	23.3	23.4	—	18.5	22.7	—	—	—
	Ss_i	0.8	0.8	1.0	1.3	2.1	—	—	0.3	—	—	—
Sea catfish,	n_i	314	393	463	344	303	229	229	154	66	47	37
Arius felis	nm_i	236	323	394	283	258	205	202	136	58	43	33
	$\bar{Sl}_i$	24.8	26.2	27.8	29.4	30.7	32.1	32.7	33.9	33.9	33.5	33.3
	Ss_i	3.4	2.8	2.6	2.7	3.1	3.0	3.3	3.5	4.1	4.6	3.7
Pinfish,	n_i	1,272	617	343	112	88	8	17	14	8	2	2
Lagodon rhomboides	nm_i	1,230	581	315	108	82	7	15	13	8	2	2
	$\bar{Sl}_i$	16.5	16.6	16.9	17.3	16.6	15.8	15.9	17.6	16.6	18.0	17.0
	Ss_i	1.3	1.8	2.1	2.7	2.6	2.3	1.4	2.0	1.6	0.0	0.0
Atlantic croaker,[1]	n_i	731	741	479	134	182	70	24	7	3	1	3
Micropogon undulatus	nm_i	450	602	378	107	155	55	23	7	3	1	3
	$\bar{Sl}_i$	22.6	24.5	26.1	28.5	29.6	31.2	32.5	35.0	32.7	25.0	24.5
	Ss_i	1.3	1.6	1.8	1.6	2.4	2.5	3.2	2.7	5.6	—	11.4
Blue runner,[1]	n_i	439	468	500	140	77	47	58	32	13	4	4
Caranx crysos	nm_i	392	429	477	122	62	46	52	31	12	4	3
	$\bar{Sl}_i$	21.1	22.4	24.5	26.6	29.5	32.5	36.3	37.4	32.6	29.7	27.2
	Ss_i	1.4	1.7	2.1	3.0	4.2	4.3	4.4	3.4	8.4	9.2	11.2
Pigfish,[1]	n_i	617	359	127	36	3	1	2	0	0	2	0
Orthopristis chrysoptera	nm_i	597	346	124	36	3	1	2	0	0	2	0
	$\bar{Sl}_i$	18.1	19.5	21.0	21.8	22.5	24.5	20.0	—	—	17.5	—
	Ss_i	0.7	1.0	0.9	1.3	1.8	—	0.7	—	—	0.7	—
Bluefish,[1]	n_i	148	247	287	164	69	95	46	25	8	11	4
Pomatomus saltratrix	nm_i	138	236	279	148	67	91	46	22	7	11	4
	$\bar{Sl}_i$	30.1	31.9	33.4	36.3	38.7	39.1	41.4	38.9	40.6	35.6	31.0
	Ss_i	3.8	3.8	3.5	3.9	3.4	4.0	3.7	7.1	5.9	11.0	4.4
Spanish mackerel,[1]	n_i	146	109	145	133	101	81	41	27	17	8	5
Scomberomorus maculatus	nm_i	126	91	130	108	81	78	38	26	15	5	5
	$\bar{Sl}_i$	33.4	34.5	36.0	38.1	39.7	42.2	44.5	45.7	47.4	44.6	49.1
	Ss_i	4.9	4.7	4.8	4.9	5.0	4.9	4.2	4.3	7.9	9.1	7.4
Yellowfin menhaden,[1]	n_i	2	4	28	100	224	191	170	49	10	12	1
Brevoortia smithi	nm_i	2	3	28	94	204	182	161	44	10	12	1
	$\bar{Sl}_i$	23.0	24.3	24.4	25.5	25.8	26.5	26.4	26.6	28.5	28.4	31.0
	Ss_i	4.9	0.8	1.2	1.3	1.1	1.1	1.2	1.0	1.7	1.5	—
Gafftopsail catfish,[1]	n_i	2	5	10	14	15	12	7	24	41	50	85
Bagre marinus	nm_i	2	5	10	14	15	12	5	24	41	50	81
	$\bar{Sl}_i$	39.7	43.3	45.1	40.4	41.8	40.2	39.9	41.7	42.9	43.8	44.6
	Ss_i	3.2	1.7	5.3	5.7	5.7	6.5	5.0	4.3	3.9	3.4	4.1
Spotted seatrout,[1]	n_i	77	66	32	26	14	13	11	3	1	1	1
Cynoscion nebulosus	nm_i	70	59	28	22	12	13	11	3	1	1	1
	$\bar{Sl}_i$	30.3	32.7	36.3	38.6	43.7	45.5	47.8	50.7	54.0	57.0	36.5
	Ss_i	2.7	4.1	3.1	3.6	3.6	4.3	3.8	7.2	—	—	—
Crevalle jack,[1]	n_i	64	28	26	17	10	12	18	8	26	23	1
Caranx hippos	nm_i	63	27	26	17	10	12	18	8	26	23	0
	$\bar{Sl}_i$	16.2	18.5	19.0	19.9	29.1	33.8	31.3	22.8	37.2	41.8	—
	Ss_i	0.9	3.0	1.0	5.9	9.3	6.8	3.6	5.6	2.6	10.3	—
Little tunny,	n_i	24	8	25	30	6	6	6	16	23	12	26
Euthynnus alletteratus	nm_i	24	8	25	29	5	6	4	15	23	10	26
	$\bar{Sl}_i$	42.3	51.2	44.6	58.3	58.3	60.5	57.4	59.0	58.8	54.6	57.3
	Ss_i	17.8	12.6	15.8	7.3	1.7	1.8	4.0	3.8	2.4	10.9	8.0
Atlantic sharpnose shark,	n_i	6	15	19	18	15	17	21	15	7	9	7
Rhizoprionodon terraenovae	nm_i	6	11	18	18	14	16	20	14	7	9	7
	$\bar{Sl}_i$	50.4	59.1	61.5	60.0	63.6	65.8	62.6	72.4	72.6	72.1	74.8
	Ss_i	4.1	14.6	10.1	12.2	11.6	13.1	11.9	10.4	6.0	13.3	9.8
Atlantic bumper,	n_i	61	64	17	2	3	1	0	0	2	0	1
Chloroscombrus chrysurus	nm_i	61	63	17	2	3	1	0	0	2	0	1
	$\bar{Sl}_i$	15.0	15.6	15.7	16.5	17.7	17.0	—	—	19.2	—	15.5
	Ss_i	1.2	1.1	1.8	2.8	1.8	—	—	—	4.6	—	—

TABLE 1.—Continued.

Species		m_i in centimeters and (inches) 6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)	10.2 (4.0)	10.8 (4.25)	11.4 (4.5)	12.1 (4.75)	12.7 (5.0)
Florida pompano,[1]	n_i	0	2	7	11	14	20	19	18	19	20	18
Tachinotus carolinus	nm_i	0	2	7	10	13	20	19	18	19	20	18
	$\bar{Sl}_i$	—	22.2	18.9	19.1	21.0	23.4	25.3	27.6	29.8	31.4	32.4
	Ss_i	—	3.9	1.7	1.5	4.2	3.0	3.9	2.4	2.9	2.1	3.9
Inshore lizardfish,	n_i	60	41	11	4	4	0	3	1	4	1	1
Synodus foetens	nm_i	51	36	11	4	3	0	3	1	4	1	1
	$\bar{Sli}$	36.1	38.6	39.6	39.5	33.5	—	35.0	26.0	31.2	33.5	38.0
	Ss_i	2.9	2.5	3.0	2.5	5.8	—	6.0	—	2.5	—	—
Gulf flounder,[1]	n_i	3	1	4	1	9	8	16	8	23	25	28
Paralichthys albigutta	nm_i	3	1	4	1	8	8	14	8	23	23	28
	$\bar{Sl}_i$	24.8	30.0	25.1	24.5	28.9	28.3	30.9	30.2	32.3	33.9	36.4
	Ss_i	8.3	—	3.3	—	6.1	3.7	4.7	3.3	3.1	4.2	3.8
Bonnethead shark,	n_i	0	3	0	3	10	14	20	11	15	22	29
Sphyrna tiburo	nm_i	0	3	0	3	10	14	20	11	15	22	28
	$\bar{Sl}_i$	—	90.0	—	81.8	86.1	89.7	89.1	86.4	84.5	90.2	89.7
	Ss_i	—	13.1	—	11.3	17.0	14.4	10.6	12.8	15.1	7.7	10.0
Ladyfish,[1]	n_i	49	21	17	4	6	1	1	3	4	4	2
Elops saurus	nm_i	36	19	14	2	6	1	1	2	3	3	2
	$\bar{Sl}_i$	35.1	42.3	42.8	46.5	41.8	36.5	26.5	47.7	32.8	31.3	38.2
	Ss_i	4.7	5.0	4.4	6.4	2.2	—	—	8.1	11.8	7.9	3.9
Sand seatrout,[1]	n_i	63	14	14	2	3	1	3	0	0	1	1
Cynoscion arenarius	nm_i	49	12	14	2	3	1	2	0	0	1	1
	$\bar{Sl}_i$	29.7	32.1	33.5	35.2	31.3	20.0	24.2	—	—	54.0	26.0
	Ss_i	2.9	1.4	5.1	2.5	6.8	—	1.8	—	—	—	—

[1]Caught commercially in gill nets (National Marine Fisheries Service 1974).

are caught in gill nets increase with an increase in mesh size seemed probable at least over part of the range of mesh sizes, for 20 of the 22 species (Figure 1). The two species that did not show a definite increase in mean length with an increase in mesh size were little tunny, *Euthynnus alletteratus,* and bonnethead shark, *Sphyrna tiburo.* Of the 22 species, none was caught (in numbers where $nm_i > 9$) in every mesh size. The relation of an increase in mean length for 20 species (little tunny and bonnethead shark excluded) with an increase in mesh size did not hold throughout the range of mesh sizes for gulf menhaden, *Brevoortia patronus;* sea catfish, *Arius felis;* pinfish, *Lagodon rhomboides;* blue runner, *Caranx crysos;* bluefish, *Pomatomus saltatrix;* gafftopsail catfish, *Bagre marinus;* crevalle jack, *Caranx hippos;* Atlantic sharpnose shark, *Rhizoprionodon terraenovae;* and yellowfin menhaden, *Brevoortia smithi.* The primary reason for low catches in some mesh sizes and for length not increasing progressively with increasing mesh size was that the length ranges in the fished populations of many species were not great enough to provide the sizes of fish that many of the mesh sizes would efficiently capture. The two species not showing the expected relation usually were entangled or enmeshed in the webbing in an abnormal manner. Most of the little tunny that were caught were too large to determine mean length-mesh size relations in the mesh

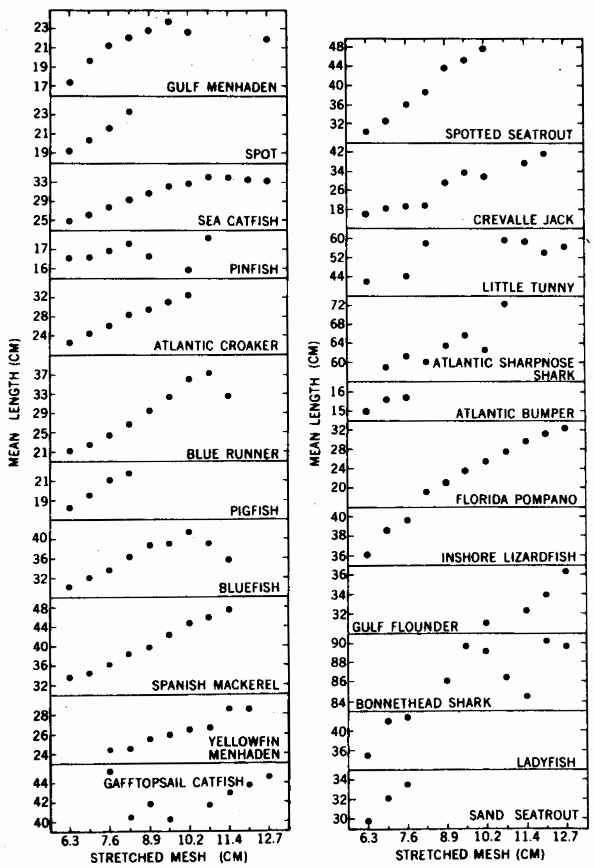

FIGURE 1.—Mean lengths of fishes caught in gill nets of various mesh sizes.

sizes used and were usually caught entangled by their snout and caudal fin; they were rarely wedged in the meshes. Bonnethead sharks were almost always caught in meshes that had been cut (probably by the sharks) and with their teeth entangled in adjacent meshes; because of these circumstances we did not expect a correlation between the size of shark and mesh size.

Based on the data requirements of Holt's method, only the 10 most abundant species (Table 1) were selected to evaluate one or more of the three assumptions—normality of selection curve, linearity of mean length-mesh size relation, and constancy of standard deviation between mesh sizes—required for Holt's model. For these species, length-frequency distributions for those mesh sizes where $n_i > 50$ are shown in Appendix Tables 1-3. These distributions are provided as the basis for our evaluation of selectivity and for applying other mathematical models to the data if other investigators so desire.

SPECIES CAUGHT IN GREATEST ABUNDANCE

Normality of Selection Curves

Natural logarithms of the ratios ($\ln R_{i+1,i,j}$) of numbers of fish of length l_j caught in meshes m_{i+1} and m_i were plotted against lengths of fishes to test normality of the selection curves. Least squares regression equations were computed, and the intercepts (a) and slopes (b) of these equations are shown in Table 2.

Best fits of the points to the straight lines were obtained for spot, *Leiostomus xanthurus;* pigfish, *Orthopristis chrysoptera;* Atlantic croaker; and blue runner. The mean values of $s_{y.x}$ [standard deviation of Y (ratio) for fixed X (length) in linear regression analysis (Steel and Torrie 1960)] were lowest for these four species and ranged from 0.211 to 0.319 (Table 2). Slight curvilinearity appeared, however, in the data for the 7.0/6.3 and 7.6/7.0 cm

TABLE 2.—Coefficients of, and estimates from, least squares regression equations of $\ln R_{i+1,i,j}$ on length by species and mesh-size pair, and k values by species.

Species	Stretched-mesh size (cm) (m_i)	a	b	$s_{y.x}$	Calculated mean selection length (l_i in cm)	Standard deviation of selection curve (s_i)
Gulf	6.3				17.52	
menhaden	7.0/6.3	−27.87	1.51	0.512		1.08
	7.0				19.27	
	7.6/7.0	−25.75	1.25	0.669		1.17
	7.6				21.02	
	8.2/7.6	−20.27	0.90	0.259		1.38
	8.2				22.78	
	8.9/8.2	−17.28	0.73	0.146		1.55
	8.9				24.53	
	9.5/8.9	−29.41	1.20	0.303		1.23
	9.5				26.28	
		Mean $s_{y.x}$ = 0.377			k = 2.759	
Spot	6.3				19.20	
	7.0/6.3	−32.27	1.60	0.337		1.10
	7.0				21.12	
	7.6/7.0	−34.28	1.55	0.302		1.11
	7.6				23.05	
		Mean $s_{y.x}$ = 0.319			k = 3.024	
Sea	6.3				22.52	
catfish	7.0/6.3	− 9.62	0.38	0.917		2.36
	7.0				24.77	
	7.6/7.0	− 6.45	0.24	0.840		3.01
	7.6				27.03	
	8.2/7.6	− 8.64	0.29	0.042		2.71
	8.2				29.28	
	8.9/8.2	− 8.09	0.26	0.354		2.91
	8.9				31.53	
	9.5/8.9	−10.40	0.32	0.202		2.66
	9.5				33.78	
	10.2/9.5	− 5.65	0.17	0.260		3.73
	10.2				36.03	
	10.8/10.2	− 6.62	0.18	0.151		3.55
	10.8				38.28	
		Mean $s_{y.x}$ = 0.395			k = 3.546	
Pinfish	6.3				19.03	
	7.0/6.3	− 3.30	0.16	0.607		3.40
	7.0				20.94	
	7.6/7.0	− 2.76	0.13	0.281		3.86
	7.6				22.84	
		Mean $s_{y.x}$ = 0.444			k = 2.997	

TABLE 2.—Continued.

Species	Stretched-mesh size (cm) (m_i)	a	b	$s_{y.x}$	Calculated mean selection length (l_i in cm)	Standard deviation of selection curve (s_i)
Atlantic croaker	6.3				22.40	
	7.0/6.3	−23.48	1.00	0.296		1.50
	7.0				24.64	
	7.6/7.0	−18.58	0.72	0.312		1.76
	7.6				26.88	
	8.2/7.6	−41.74	1.50	0.335		1.22
	8.2				29.12	
		Mean $s_{y.x}$ = 0.314			k = 3.527	
Blue runner	6.3				20.94	
	7.0/6.3	−16.18	0.74	0.153		1.69
	7.0				23.03	
	7.6/7.0	−22.80	0.97	0.541		1.49
	7.6				25.12	
	8.2/7.6	−18.84	0.70	0.186		1.71
	8.2				27.22	
		Mean $s_{y.x}$ = 0.293			k = 3.297	
Pigfish	6.3				18.09	
	7.0/6.3	−33.77	1.78	0.305		1.01
	7.0				19.90	
	7.6/7.0	−46.96	2.26	0.117		0.89
	7.6				21.71	
		Mean $s_{y.x}$ = 0.211			k = 2.849	
Bluefish	6.3				28.54	
	7.0/6.3	− 2.94	0.11	0.198		5.39
	7.0				31.39	
	7.6/7.0	− 7.27	0.22	0.582		3.59
	7.6				34.25	
	8.2/7.6	− 7.94	0.21	0.312		3.58
	8.2				37.10	
	8.9/8.2	− 9.81	0.24	0.422		3.35
	8.9				39.96	
		Mean $s_{y.x}$ = 0.378			k = 4.495	
Spanish mackerel	6.3				30.84	
	7.0/6.3	− 3.25	0.09	0.404		5.54
	7.0				33.92	
	7.6/7.0	− 1.89	0.06	0.673		7.60
	7.6				37.00	
	8.2/7.6	− 4.01	0.11	0.316		5.45
	8.2				40.09	
	8.9/8.2	− 1.36	0.03	0.586		9.71
	8.9				43.17	
	9.5/8.9	− 5.61	0.13	0.436		4.96
	9.5				46.26	
		Mean $s_{y.x}$ = 0.483			k = 4.856	
Yellowfin menhaden	8.2				24.58	
	8.9/8.2	−16.13	0.67	0.427		1.73
	8.9				26.47	
	9.5/8.9	− 8.32	0.31	0.228		2.50
	9.5				28.38	
	10.2/9.5	−13.00	0.49	0.335		2.06
	10.2				30.25	
		Mean $s_{y.x}$ = 0.330			k = 2.978	

mesh-size pairs for blue runner and in the 7.6/7.0 cm mesh-size pair for Atlantic croaker. Spot, pigfish, and Atlantic croaker were almost always caught wedged tightly in the meshes of gill nets. Blue runner were also usually caught in this manner. Occasionally, however, blue runner were caught by the dorsal antrorse spine which hooks over one or more bars of the mesh or meshes. If the spine were not present, these fish could pass through the meshes. Blue runner caught in this manner probably contributed greatly to the variation about regression.

Acceptable fits of the data, at least for most mesh-size pairs, were obtained for gulf and yellowfin menhaden. The normal curve, although acceptable, did not appear to be the most appropriate model to describe selectivity for gulf and yellowfin menhaden because of observed curvilinearity. Values of $s_{y.x}$ were smallest for gulf menhaden in the mesh-size pairs (8.2/7.6, 8.9/8.2 cm; Table 2) that did not exhibit strong curvilinearity. Gulf and yellowfin menhaden were usually caught tightly wedged in the meshes at or near maximum girth, but occasionally the larger individuals taken from a particular mesh size were caught loosely in a mesh by the opercle or preopercle. The slight positive skews observed in the length-frequency distributions (Appendix

Tables 1, 2) for two of the smallest mesh sizes for gulf menhaden and all mesh sizes for yellowfin menhaden probably resulted from fish that were caught by the opercles. This in turn probably accounts for the curvilinearity of the data observed for the two species of menhadens. A cubic exponential equation such as that proposed by Olsen (1959) might more accurately and precisely define selectivity for gulf and yellowfin menhaden over part of the length range of the selectivity curve.

The normal curve also provided acceptable approximations to the data for sea catfish and bluefish, although refinements in data collection procedures, indicating how each fish was caught, are needed to evaluate more accurately the model. Sea catfish are frequently caught entangled by the pectoral and dorsal spines, and bluefish are frequently caught enmeshed or entangled by their teeth, maxillaries, preopercles, and opercles.

The normal curve did not provide acceptable approximations to the data for pinfish and Spanish mackerel. Pinfish were usually caught dorsally by the dorsal antrorse spine and ventrally between a point perpendicular to the antrorse spine and the posterior end of the anal fin. With the fish and webbing interacting in this fashion, the probability of a given size of pinfish being caught was probably about equal in a small range of mesh sizes. The girth of a Spanish mackerel increases gradually from its snout to the anterior point of its second dorsal fin. Most individuals are caught wedged in the mesh at any point between just behind the opercle and the point of maximum girth. The point of retention, therefore, is dependent upon the mesh size within a small range of mesh sizes. Also, many are entangled by the teeth, maxillaries, and occasionally by the tail.

Attempts to suggest models which might better define selectivity for sea catfish, bluefish, pinfish, and Spanish mackerel were not made in this study, because the position at which each fish was wedged in the net and—for those fish not wedged in the net—the position at which each fish was entangled was not recorded, and additional catches of bluefish and Spanish mackerel were needed. Holt (1963) suggested that, for species that are caught at two or more distinct positions along their body, selectivity could be defined by regarding the selection curve as the algebraic sum of two or more normal selection curves, or by fitting an empirical curve such as the cubic exponential. Hamley and Regier (1973) found that the selectivity curve for walleyes was bimodal; they resolved this curve into two unimodal components representing fish that were caught by wedging and entangling.

Mean Length-Mesh Size Relation

The second assumption of Holt's method is that mean length of captured fish is proportional to mesh size. To test this assumption, $-2a/b$ was plotted against the sum of mesh sizes $(m_{i+1} + m_i)$ for each mesh-size pair (data from Table 2) and for the seven species for which data for at least three mesh-size pairs were available (Figure 2). Mean selection length (a/b or $\bar{l}_i$) in relation to mesh size can also be determined from Figure 2 using the bottom and right-hand scales. Data for Spanish mackerel were plotted even though the assumption of normality (previous section) for this species was rejected. The straight lines in Figure 2 were fitted through the origin by the least squares method and the slopes (k) of these lines are given in Table 2. With k determined, the mean selection length ($\bar{l}_i$) for any mesh size is determined by $\bar{l}_i = m_i k$.

Best fits of the data were obtained for Atlantic croaker, blue runner, and yellowfin menhaden, and acceptable fits were obtained for gulf menhaden and sea catfish. More data are required, however, to determine the degree of fit for the remaining five species (bluefish, Spanish mackerel, and the three species not shown in Figure 2). Although the degree of fit cannot be evaluated for the five species, information presented in Figure 2 or Table 2 can be used to provide rough estimates of mean selection length in relation to mesh size for bluefish, pinfish, spot, pigfish, and Spanish mackerel. Much of the deviation about the regression for bluefish (and possibly sea catfish) probably resulted from fitting the line through the origin (Figure 2). Apparently the mesh size-mean length relation is not linear throughout a range of mesh sizes between 0 and 8.6 cm for bluefish. A more reasonable approximation of the mean length-mesh size relation for bluefish might result by fitting a regular linear regression equation ($Y = a + bX$ rather than $Y = bX$) to the points in Figure 2. For pinfish, spot, and pigfish, rough approximations of the mean length-mesh size relations can be obtained using the k value (Table 2) even though each k was based on only two points and the origin. Variability about regression was great for Spanish mackerel but this information

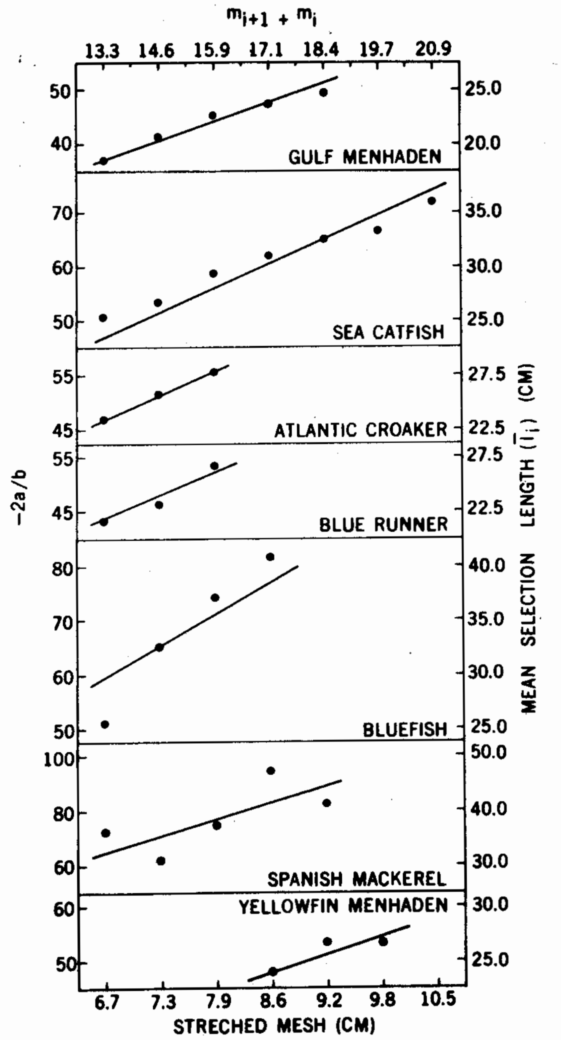

FIGURE 2.—Regression of $-2a/b$ on the sum of mesh sizes ($m_{i+1} + m_i$) and estimates of mean selection length by mesh size for seven species of fishes.

was the best available to estimate the mean length-mesh size relation.

Standard Deviation-Mesh Size Relation

The third assumption of Holt's method is that the standard deviations of length between mesh sizes estimate a common standard deviation. Standard deviations for the selectivity curves are shown in Table 2 by species and mesh-size pair. Standard deviations tended to: increase with an increase in mesh size for gulf menhaden, sea catfish, and Spanish mackerel; decrease with an increase in mesh size for bluefish; and show no apparent trend in relation to mesh size for Atlantic croaker, blue runner, and yellowfin menhaden. Although only two estimates were available for each species, standard deviations appeared similar between mesh-size pairs for spot and pigfish and increased with an increase in mesh size for pinfish.

Standard deviations were much smaller for the species that were usually wedged in the meshes (gulf menhaden, spot, Atlantic croaker, blue runner, pigfish, and yellowfin menhaden) than for those species that were frequently entangled in the meshes or caught at different girths along the body (sea catfish, pinfish, bluefish, and Spanish mackerel).

SPECIES CAUGHT IN LESSER ABUNDANCE

Twelve other species were caught in sufficient numbers to warrant general comments (Table 1, Figure 1). Florida pompano, *Trachinotus carolinus;* spotted seatrout; inshore lizardfish, *Synodus foetens;* ladyfish, *Elops saurus;* and sand seatrout, *Cynoscion arenarius,* usually were enmeshed in the webbing near their maximum girth, although the latter four species sometimes were entangled by their teeth; gulf flounder, *Paralichthys albigutta,* usually were enmeshed just behind the opercle; crevalle jack and Atlantic bumper, *Chloroscombrus chrysurus,* usually were enmeshed but frequently were restricted by the antrorse spine as described for blue runner; gafftopsail catfish usually were enmeshed in the larger mesh sizes but often were entangled by pectoral and dorsal spines in the smaller mesh sizes; little tunny and Atlantic sharpnose and bonnethead sharks usually were entangled in the webbing by their teeth and fins. In general, the magnitude of the standard deviations reflects the amount of entanglement. Standard deviations were lowest for those species normally caught wedged in the meshes and highest for those that were frequently caught entangled (Table 1).

Three of the above-mentioned species—spotted seatrout, Florida pompano, and sand seatrout—are important in the gill net fisheries along the Gulf of Mexico. Although selectivity was not evaluated for these species, owing to insufficient data, estimates of the mean length-mesh size relation can be made from the data in Figure 1. The mean length plotted in Figure 1 would unbiasedly estimate this relation only if equal numbers of fish of each length class and species were available in the fished population—an assumption that is not valid. Based on the low standard deviations in length for each mesh size (Table 1), however, it appears that a particular mesh size would efficiently capture any of these three species only over narrow length ranges. When this situation exists, only a small amount of bias in the mean length-mesh size relation results from using the estimates derived by plotting the empirical data.

DISCUSSION

Information presented in this paper can be used in fisheries management and research, and by commercial fishermen, in the following ways. We categorized the uses into two types: mesh-size regulations and capture efficiency.

Mesh-Size Regulations

Mesh-size regulations in a fishery should serve specific purposes. These regulations can be useful in controlling the size of captured individuals for some species but not others, depending upon the range in lengths of fish that a given mesh size captures with high efficiency. For species where the regulation can be useful (as indicated by low values of Ss_i or s_i), the objective of the regulation is usually to protect from harvest individuals of a species below a certain length without decreasing efficiency in the commercial gill net fishery. Determination of the smallest mesh size that can be fished is critical for the fish population and for the fishermen. If the mesh size is too small, a significant portion of the small individuals which are to be protected will be caught. If the mesh size is too large, the fishermen will possibly be prevented from using a mesh size which would result in high capture efficiency on legal-sized fish in the population. Information presented in Tables 1 and 2 and Figures 1 and 2 can be used, with various degrees of reliability, to evaluate the usefulness of mesh-size regulations and, for some of the 22 species, to estimate the mesh size which would best fulfill the above stated objective.

At least small amounts of gill net selectivity information were provided on 15 species (Table 1) of fish that were caught and sold by commercial fishermen along the south Atlantic and Gulf of Mexico. The probability that the size composition of the populations for some of these species will eventually be controlled, partially by mesh-size regulations, is high. Of the 15 species, the sizes of individuals caught by gill nets can be controlled, possibly to a degree required for management purposes, by mesh-size regulations, except for bluefish and Spanish mackerel, based on the available data. The degree of control, and the effect that a particular regulation would have on capture efficiency for legal-sized fish in the fishery, can be estimated from values of Ss_i or s_i.

Assuming that a mesh-size regulation is desirable to manage a particular fishery, the steps in estimating the "optimum" mesh size are as follows for two examples—Atlantic croaker and Florida pompano. These two species were selected as examples because, for croaker, data were sufficient to derive selectivity curves and, for pompano, we had insufficient data to derive the curves.

1. Based on management objectives, determine the maximum length (L) of fish which you want to protect from harvest (minimum length of fish to be harvested) and the percent of catch allowed below this length. We arbitrarily selected a length of 20 cm, and <2.5% as the maximum percent allowable of fish below 20 cm, for each species.

2. For Atlantic croaker, the slope (k) for the equation relating mesh size (m_i) and mean selection length ($\bar{l}_i$), and a weighted mean of the s_i estimates of the selectivity curves (Table 2) were used to determine an estimate of the required mesh size. The calculations follow:

   A. determine $s = \sqrt{\Sigma(n_i + n_{i+1})s_i^2/\Sigma n_i} = 1.56$
   B. determine the minimum mesh size (mm_i) $mm_i = (L + 2s)/k = (20 \text{ cm} + 3.11)/3.527 = 6.5$ cm.

Based on the above, one would expect about 2.5% of the total catch to be composed of Atlantic croaker under 20 cm total length by a gill net having a stretched-mesh size of 6.5 cm.

3. For Florida pompano, appropriate equations to determine $\bar{l}_i$ and s_i are not available, because selection curves could not be determined. These values can be estimated, however, if we assume that the empirical means and standard deviations ($S\bar{l}_i$ and Ss_i; Table 1) are reasonable estimates of $\bar{l}_i$ and s_i. Estimates of the mean length-mesh size relation and standard deviations based on the above assumption would probably yield reasonable and useful approximations for Florida pompano, because: A) the length range within which the pompano were caught efficiently in a

particular mesh size was narrow; B) they rarely became entangled in the webbing; and C) a wide range of sizes was available in the fished population (Table 1). Based on the above assumption, the equations are:

A. $Ss = \sqrt{\Sigma n_i Ss_i^2 / \Sigma n_i} = 3.12$
based on data where $n_i > 9$ and
B. $mm_i = (L + 2Ss)/Sk = (20 \text{ cm} + 6.24)/2.517$
$= 10.4$ cm

where Sk = the slope of the least squares regression line fitted through the origin to the points shown in Figure 1 for Florida pompano. Thus, 2.5% of the catch of pompano in gill nets with mesh size of 10.4 cm can be expected to be below 20 cm in length.

Capture Efficiency

Several factors should be considered in the selection of mesh sizes for maximizing the efficiency of capture. Efficiency of capture is defined, or measured by, the dollar return per unit of effort in a gill net fishery. In a gill net fishery the more important factors include: 1) whether individuals of a single species or a group of species are sought; 2) the regulations (mesh size, minimum size limit, etc.) that exist in the fishery; 3) how the gill net is to be fished (anchored, drift, run-around, etc.); 4) values of the species sought and values of various-sized individuals in the fished populations; 5) information on the life history of each species sought, especially the mean length of each age class, the variation in year-class strength between years, and the length-weight relation; 6) the ability, in terms of cost, to use nets with more than one mesh size; and 7) the most efficient mesh sizes for capturing various lengths of fish in the fished population. For this discussion the only factor to be considered is the determination of efficient mesh sizes.

For the 15 species of fish of commercial importance shown in Table 1, the efficiency of capturing a particular length group with maximum efficiency is highly dependent on mesh size for all except bluefish and Spanish mackerel. The range in lengths of fish that a particular mesh size would capture with high efficiency can be estimated from values of s_i or Ss_i given in Tables 1 and 2. The equations,

$$m_i = \frac{\bar{l}_i}{k} \text{ or } m_i = \frac{S\bar{l}_i}{Sk}$$

similar to those in the previous section, and with the same reservations regarding the accuracy of the estimates, can be used to estimate the most efficient mesh sizes for capturing various lengths of fish. A discussion of this type of application in a particular fishery was given by Trent and Hassler (1968).

Limitations on Uses

Selectivity information derived for the 10 species in this study as shown in Figure 1 should be used cautiously, if at all, in adjusting length-frequency distributions. The assumption that the shapes and amplitudes of the selectivity curves are the same for a species could not be tested, but is probably not valid (Hamley and Regier 1973). Further, for all species except Atlantic croaker and blue runner to which we have applied Holt's method, one or more of the three assumptions were invalid, or questionable, or sufficient data were not available to evaluate the assumptions.

Several other factors, not investigated in this study, should be considered when applying our results to estimate mesh sizes for controlling capture efficiency or in adjusting length-frequency distributions of the catch. Selection is dependent to some extent on factors other than mesh size. We used set gill nets, all of which were constructed in the same manner from one type of webbing material. Fishing often occurs with gill nets by encircling the schools or by blocking an area and scaring the fish into the net, or waiting until falling tides force the fish from the blocked area. When fishing is conducted in these ways, many individuals are often caught loosely wedged (Garrod 1961) or loosely entangled in the net; most of these fish, if set gill nets had been used, would have eventually escaped. Selection (size of captured individuals, or efficiency of capture, or both) is also dependent on other factors: natural or synthetic webbing (Washington 1973); color of webbing (Jester 1973); twine size (Hansen 1974); and the hanging coefficient (Hamley 1975).

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APPENDIX TABLE 1.—Length-frequency distributions by mesh size for Gulf menhaden, spot, pinfish, and pigfish.

Length midpoint (cm)	Stretched mesh size in centimeters and (inches)								
	6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)	6.3 (2.5)	7.0 (2.75)	7.6 (3.0)
	n_{ij}								
	Gulf menhaden						Spot		
14.0	1.0								
14.5	1.0								
15.0	4.2								
15.5	7.3								
16.0	60.5	1.1	1.3	1.1					
16.5	86.6	3.2					3.6		
17.0	201.3	19.5	2.5	2.1		1.1	17.0		
17.5	134.5	43.2		2.1			44.8		
18.0	110.6	76.7	1.3	1.1			187.7	4.5	
18.5	43.8	87.5	3.8	1.1		1.1	288.2	15.7	1.1
19.0	35.5	121.0	21.4	1.1	2.4		491.7	81.7	1.1
19.5	17.7	127.5	41.6	2.1	2.4		370.6	149.9	2.1
20.0	11.5	128.6	114.7	9.7	3.6		256.8	277.5	10.6
20.5	10.4	85.4	163.9	24.7	7.2	1.1	105.4	211.5	17.0
21.0		84.3	273.6	92.3	13.2	1.1	41.2	176.8	27.6
21.5		44.3	249.6	148.2	34.9	2.2	18.2	83.9	30.8
22.0		32.4	230.7	189.0	66.1	4.4	4.8	33.6	43.5
22.5		25.9	128.6	168.6	66.1	5.6		11.2	21.2
23.0		6.5	64.3	97.7	63.7	8.9		6.7	9.6

APPENDIX TABLE 1.—Continued.

Length midpoint (cm)	Stretched mesh size in centimeters and (inches)								
	6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)	6.3 (2.5)	7.0 (2.75)	7.6 (3.0)
	n_{ij}								
	Gulf menhaden						Spot		
23.5		5.4	26.5	52.6	62.5	15.6		1.1	4.2
24.0		1.1	5.0	26.8	32.4	25.6			3.2
24.5		2.2	8.8	16.1	26.4	11.1			
25.0				5.4	14.4	10.0			
25.5		1.1		2.1	8.4	10.0			
26.0				1.1	2.4				
26.5			1.3		2.4	1.1			
27.0					1.2				
27.5					1.2				
	Pinfish						Pigfish		
8.0					1.1				
9.0		1.1							
9.5		1.1							
10.0		1.1							
11.0	1.0		1.1	1.0					
11.5	3.1	4.2			1.1				
12.0	7.2	4.2	1.1						
12.5	2.1	3.2	1.1	1.0					
13.0	5.2	4.2	6.5		4.3				
13.5	23.8	12.7	5.4	1.0	2.1				
14.0	43.4	21.2	10.9	1.0	4.3				
14.5	51.7	18.0	20.7	8.3	4.3		1.0		
15.0	91.0	63.7	21.8	9.3	5.4				
15.5	90.0	51.0	28.3	11.4	10.7		1.0		
16.0	139.6	82.8	33.8	7.2	7.5		3.1		
16.5	194.4	48.8	39.2	13.5	8.6		12.4	1.0	
17.0	264.7	70.1	37.0	10.4	7.5		66.1	3.1	
17.5	167.5	52.0	35.9	12.4	6.4		109.6	6.2	
18.0	124.1	59.5	29.4	11.4	3.2		186.0	24.9	3.1
18.5	30.0	38.2	6.5	6.2	6.4		132.3	42.5	1.0
19.0	23.8	45.7	5.4	1.0	4.3		71.3	70.6	
19.5	2.1	24.4	22.9		2.1		24.8	71.6	4.1
20.0	4.1	6.4	9.8	3.1	1.1		8.3	58.1	8.2
20.5	3.1	1.1	9.8	2.1	2.1		1.0	46.7	23.6
21.0		2.1	9.8	1.0	2.1			24.9	39.9
21.5			2.2	2.1				6.2	24.6
22.0			1.1	2.1				2.1	10.2
22.5			1.1	1.0				1.0	9.2
23.0			2.2		2.1				2.0
23.5				2.1					1.0
24.0					1.1				
26.0				1.0					
26.5				1.0					
29.0				1.0					

APPENDIX TABLE 2.—Length-frequency distributions by mesh size for sea catfish and yellowfin menhaden.

Length midpoint (cm)	Stretched mesh size in centimeters and (inches)								
	6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)	10.2 (4.0)	10.6 (4.25)	11.4 (4.5)
	n_{ij}								
	Sea catfish								
14.0	1.3								
16.5	2.6					1.1	2.2	1.1	
19.0	2.6		1.2				1.1	1.1	1.2
21.5	75.8	8.5	2.4	1.2	2.4	1.1			1.2
24.0	127.7	171.5	52.9	10.9	3.6	2.2	5.7	1.1	2.4
26.5	57.2	130.2	182.1	78.0	18.8	5.5	2.2	2.2	1.2
29.0	19.9	43.8	162.1	136.5	119.8	36.9	15.9	6.7	1.2
31.5	17.3	26.9	44.8	85.2	110.4	97.1	77.0	36.4	8.0
34.0	5.4	8.4	14.1	20.6	38.7	59.3	89.5	55.8	26.0
36.5	2.6	3.6	1.2	12.0	5.8	21.3	30.6	36.4	22.4
39.0	1.3		2.4			2.2	3.4	11.4	3.5
41.5						1.1	1.1	1.1	1.2
44.0					1.2	1.1		1.1	
46.5					1.2				
54.0					1.2				
	Yellowfin menhaden								
22.0				6.4					
23.5				39.4	25.3	8.3	4.2		
25.0				38.3	114.2	92.4	37.9		
26.5				14.9	72.5	72.3	92.9		
28.0				1.1	12.1	17.8	31.7		
29.5							2.1		
31.0							1.1		

APPENDIX TABLE 3.—Length-frequency distribution by mesh size for Atlantic croaker, bluefish, Spanish mackerel, and blue runner.

Length midpoint (cm)	Stretched mesh size in centimeters and (inches) 6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)
	n_{ij}					
			Atlantic croaker			
19.0	1.6					
19.5	1.6	1.2	1.3			
20.0	16.2	1.2			1.2	
20.5	37.5	2.5				
21.0	61.7	4.9				1.3
21.5	56.8	9.8	1.3			
22.0	125.0	17.2				
22.5	94.2	44.4	5.1			
23.0	116.9	70.2	5.1			
23.5	66.6	81.3	19.0			1.3
24.0	78.0	104.7	31.7			
24.5	27.6	104.7	36.7	0.6	1.2	
25.0	27.6	80.1	58.3	0.6	1.2	
25.5	9.7	64.1	57.0	2.3	1.2	
26.0	3.2	48.0	60.8	4.3	1.2	
26.5	3.2	35.7	53.2	4.9	7.0	
27.0	1.6	29.6	45.6	12.7	14.1	
27.5		16.0	25.3	17.4	12.9	
28.0	1.6	16.0	22.8	25.2	15.3	1.3
28.5		4.9	20.3	13.0	14.1	2.5
29.0		1.2	10.1	20.3	15.3	1.3
29.5		2.5	13.9	10.1	18.8	6.4
30.0			1.3	4.1	12.9	6.4
30.5		1.2	2.5	3.2	15.3	5.1
31.0			2.5	4.6	5.9	7.6
31.5				3.8	11.7	10.2
32.0			2.5	3.8	3.5	3.8
32.5			1.3	1.3	10.6	8.9
33.0				1.7	7.0	5.1
33.5					2.3	1.3
34.0					3.5	2.5
34.5					1.2	
35.0			1.3		3.5	2.5
35.5					1.2	
36.5						2.5
			Bluefish			
24.0	12.8	1.0				
26.5	23.5	24.1	3.0			1.0
29.0	51.5	75.4	68.0	15.4	1.0	3.0
31.5	31.0	61.7	53.4	15.4	3.0	4.0
34.0	10.8	36.6	78.3	26.6	7.2	4.1
36.5	10.7	30.2	52.4	45.5	10.3	13.8
39.0	6.5	6.2	21.6	41.0	24.8	32.8
41.5	1.1	10.4	9.0	12.1	17.5	21.1
44.0		1.0	1.0	6.6	4.1	11.6
46.5				1.1	1.0	4.0
			Spanish mackerel			
26.5	4.6	3.6			1.2	
29.0	42.9	21.6	12.2	2.4		
31.5	37.1	21.6	22.3	13.6	2.4	1.1
34.0	12.7	16.8	39.0	21.0	15.0	2.2
36.5	20.7	13.2	30.2	38.2	18.9	7.5
39.0	13.8	20.4	16.6	14.8	25.2	21.4
41.5	7.0	7.2	12.2	22.2	11.2	17.1
44.0	2.4	3.6	2.2	13.6	13.8	13.9
46.5	3.6	1.2	6.6	3.6	7.5	9.7
49.0	1.2		2.2	1.2	2.4	4.3
51.5					2.4	1.1
54.0			1.1	1.2	1.2	1.1
56.5						1.1
59.0				1.2		1.1

Length midpoint (cm)	Stretched mesh size in centimeters and (inches) 6.3 (2.5)	7.0 (2.75)	7.6 (3.0)	8.2 (3.25)	8.9 (3.5)	9.5 (3.75)
	n_{ij}					
			Blue runner			
16.5	1.1					
17.5	4.5	1.1				
18.0	4.5	1.1				
18.5	6.7					
19.0	13.4	2.2	1.0			
19.5	23.5	5.4				
20.0	63.8	18.4	2.1			
20.5	65.0	13.1				
21.0	82.9	50.2	5.2			
21.5	42.6	58.9	4.2	1.1	1.2	
22.0	48.2	74.2	16.8	1.1		
22.5	29.1	79.6	31.4			2.2
23.0	23.5	58.9	69.2	4.6		
23.5	19.0	36.0	72.3	5.7		1.1
24.0	3.4	30.5	63.9	9.2		
24.5	4.5	12.0	54.5	5.7		
25.0	2.2	7.6	44.0	20.7	1.2	
25.5		6.5	18.9	14.9	10.1	
26.0		9.8	51.4	21.8	11.3	
26.5		1.1	23.1	12.6	7.5	
27.0	1.1	1.1	12.6	9.2	7.5	
27.5			11.5	8.0	1.2	
28.0			3.1	1.1		
28.5			4.2			
29.0			1.0		1.2	
29.5				1.1		
30.0			2.1	1.1	1.2	
30.5			1.0	2.3	1.2	
31.0				4.6	7.5	
31.5			1.0	1.1	3.8	1.1
32.0				6.9	3.8	2.2
32.5		1.1			1.2	1.1
33.0				2.3	6.3	1.1
33.5				1.1		1.1
34.0				1.1	1.2	3.3
34.5			1.0			2.2
35.0					1.2	4.5
36.0				1.1	2.5	4.5
36.5						4.5
37.0			2.1		2.5	4.5
37.5						2.2
36.0					1.2	3.3
36.5			1.0			2.2
39.0						1.1
39.5				1.1		3.3
40.0			1.0			5.6
40.5					2.5	1.1
41.0		1.1				2.2
42.0						1.1
42.5						1.1
44.5						1.1